Project Description

Introduction

Proton-antiproton collisions at $\sqrt{s} \approx 2$ TeV have proved to be a very fruitful tool for deepening our understanding of the Standard Model and for searching for physics beyond this framework. DØ has published more than a hundred papers from Run1[1], including the discovery and precision measurements of the top quark, precise tests of electroweak predictions, QCD tests with jets and intermediate vector bosons, and searches for supersymmetry and other postulated new particles. With the addition of a magnetic field, silicon and fiber trackers, and substantial upgrades to other parts of the detector, DØ has started Run2 with the goal of building on this broad program, taking advantage of significantly higher luminosities, and adding new measurements in b-physics. The strengths of the DØ detector are its liquid argon calorimetry, which provides outstanding measurements of electrons, photons, jets and missing transverse energy (ME_T); its large solid angle, multi-layer muon system and robust muon triggers; and its state of the art tracking system using a silicon detector surrounded by a fiber tracker providing track triggers.

A series of physics workshops [2] organized by Fermilab's Theory group together with the CDF and DØ collaborations have mapped out the physics terrain of the Tevatron in some detail. It is clear from the very large amount of work carried out in these meetings and described in the reports that integrated luminosities much higher than the $2\mathrm{fb}^{-1}$, which was the original goal of Run2, add significantly to the program. Because of the tantalizing physics prospects a higher integrated luminosity brings, the laboratory supports extended running of the Tevatron collider, called Run2b, which would deliver a total integrated luminosity of $15\mathrm{fb}^{-1}$ over the course of the full Run2. The current DØ silicon tracker was built to withstand the 2 – 4 fb^{-1} of integrated luminosity originally projected. The higher integrated luminosity now scheduled for Run2 will therefore render the inner layers of the present silicon tracker inoperable due to radiation damage. Of particular importance to being able to collect the data needed to exploit the physics potential of the Tevatron is the completion of a replacement of the silicon detector in approximately three years with minimal Tevatron down time. While all areas of physics benefit from increased statistics and improved detector performance, it is the high p_T physics program the one that benefits the most, in particular those high p_T physics studies that depend on high efficiency for tagging jets that originated from a bottom quark (b-tag). For these reasons, DØ decided to build a new silicon tracker for Run2b that is optimized for high-p_T physics processes that rely on excellent b-tagging.

The discovery of the top quark in 1995, by the DØ [3] and CDF [4] collaborations, was the culmination of nearly two decades of intense research at accelerators around the world. With samples rather limited in statistical power - tens of events after background subtraction - both collaborations have done precise measurements of the top quark properties, in particular its mass and the $t\bar{t}$ production cross section. The top quark's large mass, by far the heaviest fundamental particle known, makes it a unique probe of physics at the natural electroweak scale. Although the top quark mass is consistent with other precision electroweak measurements within the framework of the Standard Model, no fundamental explanation exists for the reasons why top quarks should be so massive. The large mass of the top quark arises from its large couplings to the symmetry breaking sector of the Standard Model. Precision measurements of the top mass, width and couplings may therefore lead to a deeper understanding of electroweak symmetry breaking and the origin of mass. Such measurements are possible in part because the top quark's natural width of 1.4GeV is much greater than the hadronization timescale set by Λ_{QCD}, causing the top quark to decay to a real W boson and a bottom quark before hadronization. The top quark can therefore be completely described by perturbative QCD, and studied as a bare quark. Precision studies of this unconventional quark are considered high priorities at hadron collider machines (Tevatron and LHC) and studies for future accelerators, and are unanimously accepted as a worldwide scientific priority.

The Standard Model predicts that top quarks are created via two independent production mechanisms in hadron colliders. The primary mode, in which a $t\bar{t}$ pair is produced from a gtt vertex via the strong interaction, was used by DØ and CDF to establish the existence of the top quark in 1995[3,4], and measure its mass. The current uncertainty of approximately 3% on the top quark mass, could be reduced to 2% during Run2a ($2fb^{-1}$) and to ~1% during Run2b ($15fb^{-1}$)[5]. The precision of these measurements is expected to be limited by systematic uncertainties. The measurement of the top quark mass therefore does not benefit enormously by the dramatic increase in integrated luminosity expected during Run2b. The second production mode of top quarks at hadron colliders is the electroweak production of a single top quark from a Wtb vertex. The predicted cross section for single top production is about half that of $t\bar{t}$ pairs, but the signal-to-background ratio is much worse. Single top quark production has therefore not yet been observed experimentally. Extracting a single top signature would be an independent confirmation of the top quark existence and a means to measure the Cabibbo-Kobayashi-Maskawa (CKM) matrix element V_{tb}, and study the Wtb coupling. Measuring the single top quark production cross section is also crucial in understanding the backgrounds to searches for the Higgs Boson and new physics beyond the Standard Model.

The Tevatron is entering a new era for top quark physics. Greatly increased statistics will be combined, in DØ, with much improved signal sample purity made possible by silicon vertex b-tagging. The discovery of single top production and the direct measurement of V_{tb} is one of the priorities of the DØ collaboration during Run2. With $2fb^{-1}$ of integrated luminosity, the cross section can likely be measured at the 20% level, allowing $|V_{tb}|$ to be extracted with a precision of 12%. With $15fb^{-1}$ this uncertainty could be roughly halved. As will be detailed in the next sections, the signatures for top pair and single top production involve intermediate vector bosons and heavy flavor jets. Prof. Gerber's extensive experience with W+jets analyses and thorough understanding of the silicon tracker put her in a unique position to take a leading role in the top physics analysis effort during Run2. This career advancement proposal is therefore centered in studying the properties of the top quark production and decay using the DØ silicon tracker and the large amount of integrated luminosity that will be available during Run2.

<u>Results from previous NSF Support</u>

Prof. Gerber's research is being supported by the following NSF grants. Both are equally relevant to the proposal.

1. PHY-0098824, "Experimental High Energy Physics Research at the D-Zero and CMS Collider Experiments", under the direction of Nikos Varelas, Cecilia E. Gerber, and Mark Adams, 08/01/2001-07/31/2004, $770,554. This grant supports Prof. Gerber's Summer Salary, and partially supports Dr. Elizaveta Chabalina and Gustavo Otero y Garzon. Additional support for Chabalina, Otero y Garzon and Bartko are available from Prof. Gerber's startup funds.

2. PHY-0116649, "MRI: Development of a Silicon Vertex Detector for the Higgs Search at the Tevatron Collider", under the direction of Alice L. Bean, Cecilia E. Gerber, Gordon T. Watts, Regina Demina, and Richard A. Partridge, 08/15/2001-04/30/2004, $1,683,566. Additional funds of $791,635 are available from cost sharing. This grant supports the purchase of equipment for DØ Run2b, one undergraduate student's salary, and a part time mechanical technician to design and set up testing stations for detector production and assembly.

Prof. Gerber's contributions to the DØ experiment during the last year have been concentrated along two fronts: analysis of data collected by the DØ detector, and development of the replacement DØ silicon tracker for Run2b. The following sections include summaries of those activities, as well as a description of her contributions to education and the development of human resources.

Data analysis (Gerber)

Prof. Gerber has been a major contributor to the analysis of data taken by the DØ detector during Run1. She developed muon identification methods for high p_T muons, and measured the inclusive W and Z production cross sections in the muon channel [6]. She then pioneered the study of W bosons produced in conjunction with jets at DØ [7], and was soon appointed convener of the DØ physics group that studies the properties of QCD, the theory of strong interactions, using W and Z boson events. The benefits of using intermediate vector bosons to study QCD are large Q^2, distinctive event signatures, low backgrounds, and a well understood electroweak vertex. Understanding the production of W and Z bosons is also important when one searches for new physics, since the backgrounds for many new processes involve W's and Z's that are produced in conjunction with high E_T jets. Six additional refereed publications[8] were produced as part of this effort. Five graduate students wrote their PhD theses on topics included in those publications: Jamal Tarazi (University of California, Irvine), Dylan Casey (University of Rochester), Gervasio Gomez (University of Maryland), Georg Steinbrueck (University of Oklahoma), and Miguel Mostafa (Instituto Balseiro, Argentina). Prof. Gerber served as local advisor of the students. In addition, she was graduate advisor to Miguel Mostafa.

The largest irreducible background to top production at the Tevatron is W+jet events. The single most effective handle to single out top events from the W+jets background is the efficient tagging of jets produced from a b-quark. Prof. Gerber's deep understanding of the W+jets signal, and her detailed knowledge of the silicon detector, put her in a unique position to take a leading role in top physics analysis at DØ during Run2. She was appointed co-convener of the top group in July 2001 by the DØ spokesmen and physics coordinator. Because the top physics group was created at that time, Prof. Gerber had to build an analysis task force from scratch. One year later, 132 physicists have joined the top group distribution list, and 30 PhD students have a thesis topic assigned within the group. In particular, Gustavo Otero y Garzon's thesis will be the study of top quarks identified by their decay to electron, neutrino + jets, with the b-jet tagged based on information from the silicon detector. The accelerator performance until now has not been optimal, and the amount of integrated luminosity collected is only a fraction of that in Run1. Because no top signal can be expected in the current data, the efforts of the group have been centered on particle identification (electrons, muons and neutrinos), and identification of b-jets.

Data analysis (Chabalina)
Dr. Elizaveta Chabalina is responsible for the online monitoring and analysis program for the DØ Run2a Silicon Microstrip Tracker (SMT), currently taking data at the Fermilab Tevatron. She has studied the behavior of the SMT response and signal-to-noise levels for the various settings allowed by the readout electronics. Based on these studies, optimal settings for the readout electronics and the offline tracking code were selected.
In addition, she is responsible for the support and development of the digitization package for the Monte Carlo simulation of the SMT response. She is currently working on the tuning of the digitization parameters (cross talk, noise) to reproduce cluster charge distributions and Lorentz angle measured from data. The goal of this study is to optimize the cuts used in the cluster reconstruction algorithms and estimate the cluster errors to be used for tracking. High quality tracking is needed before efficient b-tagging can be developed.

Silicon Projects (Gerber, Chabalina, Otero y Garzon, Bartko, Stroe)
The construction of the DØ Run2b Silicon tracker encompasses an enormous level of complexity, even for the standards of other HEP projects. This arises from the number of components in the device itself, the stringent quality control imposed by the hostile and inaccessible environment in which the detector will be operated, and the tight time scale that requires the detector to be completed in approximately three years with minimal Tevatron down time. Prof. Gerber was the leader of the DØ Run2a Silicon Microstrip Tracker testing group during the production phase of the $10M device at Fermilab's Silicon Detector Facility. The tracker was completed and installed in the DØ detector in December 2000, and Prof. Gerber was appointed leader of the DØ Run2b Silicon Tracker Testing and Quality Assurance group. Her responsibilities include developing and signing off on Quality Assurance procedures for sensors, hybrids and production methods. She is responsible for the schedule and cost estimate of the testing project, and for the chapter on Production and Testing for the DØ Run2b silicon tracker Technical Design Report.

Together with her students (Gustavo Otero y Garzon and Hendrik Bartko), and with her research associate (Dr. Elizaveta Chabalina), she is developing the testing procedures for silicon detector modules, and participating in the ongoing R&D project and design of the Run2b Silicon replacement tracker. NSF MRI funds are available to set up Data Acquisition (DAQ) stations to test detector modules during production. The UIC silicon and electronics labs are being used for the debugging and programming of the new DAQ boards that will be used for detector testing.

Dr. Chabalina is co-leader of the DØ Run2b Silicon Microstrip Tracker Simulation group. This group performed a detailed simulation of the Run2b silicon tracker, based on a full Geant simulation of the underlying physical process, data-tuned models of detector response, and complete reconstruction of simulated events, including pattern recognition, within the DØ Run2b software framework. Quantitative calculations of occupancy, impact parameter resolution, momentum resolution, and b-quark tagging efficiency are crucial to decide on detector parameters during the design phase of the DØ Run2b silicon tracker.

The amount of information that needs to be stored during the construction of the DØ Run2b silicon tracker arises mainly from the number of components in the device itself, but also on the rather large number of vendors and universities involved, and the need to maintain a stringent and uniform quality control. Cosmin Stroe, a UIC undergraduate student, is designing a production and testing database to store all the information relevant to the production and testing. A linux server has been set up at UIC for this purpose, and Stroe has designed a relational database using mySQL, where each item has its unique ID for easy identification and tracking; PHP provides a web-based interface to the database, accessible to all collaborators and commercial vendors involved in the project.

Contribution to the development of human resources

UIC is the largest institution of higher education in the Chicago area, and is recognized by its peers as a center not only of top-quality research, but also top-quality teaching and public service. UIC's student body reflects the ethnic and racial diversity of Chicago-the third largest metropolitan area in the country-with a higher percentage of African-American and Latino students than any Big Ten university. UIC is committed to helping meet Chicago's needs in education and other areas that are vital to the quality of life in the city.

The UIC HEP group engages students and postdocs in both physics analyses and hardware projects, in which they gain valuable skills. As a result of this, all of the past PhD graduates and postdoctoral fellows have launched successful careers in physics or in private corporations after they trained at UIC. The proximity of UIC to Fermilab is a unique advantage that allows graduate students resident at UIC to participate in weekly working meetings of the physics or detector groups at Fermilab, to contribute to the operation of the detector during data taking, and to use the Fermilab research facilities.

Being a Hispanic woman, Prof. Gerber has been very active in outreach and recruitment activities geared towards underrepresented groups in science and engineering. She successfully recruited Dr. Elizaveta Chabalina , and Gustavo Otero y Garzon, as a post-doc and a graduate student respectively. Recent activities include the mentoring of two UIC minority undergraduate students, Carrie Hahn and Jaime Robles. Carrie analyzed data taken by the DØ silicon detector during the Summer of 2000, and Jaime worked in the UIC silicon lab during the 2001 Spring semester. Prof. Gerber has been featured in a variety of outreach videos produced by the Fermilab visual media department, and is a member of the UIC Physics department outreach and recruitment committee.

Prof. Gerber is also engaged in QuarkNet activities. QuarkNet is an NSF funded program designed to introduce high school teachers to high energy physics. UIC joined this multi-year program in the summer of 2000. At that time, two lead high school teachers, Jackie Barge (Walter Payton High School in Chicago) and Bob Hurley (Proviso West High School in Hillside), spent eight weeks working with the HEP research group. To increase their exposure to the HEP environment, they attended the annual DØ workshop at Northern Illinois University and spent a week working on the silicon testing effort at the Fermilab Silicon Detector Facility. The also attended the QuarkNet workshop at Fermilab. In June 2001, the HEP group hosted a three-week long workshop at UIC for 13 Chicago area high school teachers. They attended talks by High Energy theorists and experimentalists, and obtained hands-on experience working on a muon lifetime experiment using scintillators to detect cosmic ray muons. In addition, participants had the opportunity to work on competitive projects developed at Fermilab, that use DØ Run1 top quark candidates to identify particles present in the events, classify them and, eventually, measure the top quark mass. Prof. Gerber continues to meet with the teachers during the year, and hosts annual visits of high school students to UIC. The students are in their majority from underrepresented groups, and the program encourages them to apply to UIC. One African American female recruited by these means was admitted to UIC as an undergraduate in the engineering college in 2001. Students are also encouraged to apply for the Saturday Morning Physics program at Fermilab.

One limitation of the current QuarkNet program is that it addresses high school students indirectly through teacher training. To improve the direct connection to the classrooms, the UIC HEP group has secured funds from the Illinois State Board of Education for teacher's classroom materials. Those funds were partially used to design and setup portable cosmic ray detectors to measure the muon's lifetime. The setups consist of a conventional large block of scintillator viewed directly by a photomultiplier tube, Crockcroft Walton HV base, data aquisition board and PC readout. These components are the fruit of a 2-year long development effort of the UIC HEP faculty, Fermilab engineering staff, and collaborators from the University of Rochester that resulted in cheap, safe and portable cosmic ray detectors for use in high schools. A second QuarkNet teachers workshop is taking place at UIC in June 2002, with all 13 teachers returning, a 100% retention rate from the previous year.

<u>Publications resulting from the NSF award</u>

Refereed publications by the DØ Collaboration can be found in reference [1]. Non-refereed publications and technical notes by Prof. Gerber and Dr. Chabalina for the period 2001-2002 are summarized below.

1. Technical Design Report for the DØ Run2b Silicon Tracker, The DØ Collaboration, *http://d0server1.fnal.gov/projects/run2b/Silicon/TDR*
2. DØ Note Number: 003962 *Results from Irradiation Tests on DØ Run2a Silicon Detectors at the Radiation Damage Facility at Fermilab*. J. Gardner, C. Gerber, Z. Ke, S. Korjanevsky, A. Leflat, F. Lehner, R. Lipton, J. Lackey, M. Merkin, P. Rapidis, V. Rykalin, E.Chabalina, L. Stutte, B. Webber
3. DØ Note Number: *003958 Studies on the Radiation Damage to Silicon Detectors For Use in the DØ Run2b Experiment*. A. Bean, J. Gardner, C. Gerber, H. Haggerty, Z. Ke, S. Korjanevsky, S. Lager, A. Leflat, F. Lehner, R. Lipton, J. Lucky, M. Merkin, P. Rapidis, V. Rykalin, E. Chabalina, L. Spiegel, L. Stutte, B. Webber
4. DØ Note Number: 003942 *Top group ROOT tuples selection and Data Quality Monitoring.* Barberis, Choi, Gerber, Iashvili, Klute, Quadt, Schwartzman
5. *Recent Electroweak Results from the Tevatron*, C. E. Gerber, for the DØ and CDF Collaborations. Proceedings of the International Europhysics Conference on High Energy Physics, July 2001, PRHEP-hep2001/126.
6. DØ Note Number: 003866 *Topological Vertex Reconstruction at DØ* S.Grinstein, C.Gerber, R.Piegaia
7. DØ Note Number: 003862 *Measurement of the ratio of the differential cross sections for W and Z boson production as a function of transverse momentum* Dylan Casey, Cecilia E. Gerber
8. DØ Note Number: 003841 *Electrical Production Testing of the DØ Silicon Microstrip Tracker Detector Modules.* Asman, Clark, Gerber, Grudberg, Hall, Leflat, Nomokonov, Mihalcea, Rizatdinova, Chabalina, Sidwell, Zverev
9. DØ Note Number: 003951 *Expanded Run 2B Silicon Simulation Studies for the December 2001 TDR* . F. Rizatdinova, E. Chabalina, A. Khanov, T. Bolton
10. DØ Note Number: 003964 *Evaluation of Alternate Designs of the Silicon Tracker* T. Bolton, E.Chabalina, R.Demina, A.Khanov, A.Nomerotski, F.Rizatdinova

CAREER Development Plan

Introduction

In the Standard Model, single top production at hadron colliders provides an opportunity to study the charged-current weak-interaction of the top quark[9]. Figure 1 shows representative Feynman diagrams for single top quark production at hadron colliders for s-channel (Fig. 1a), and t-channel production (Fig. 1b and 1c). A third process, usually called *Associate Production*, in which the top quark is produced together with a W boson, has negligible cross section at the Tevatron.

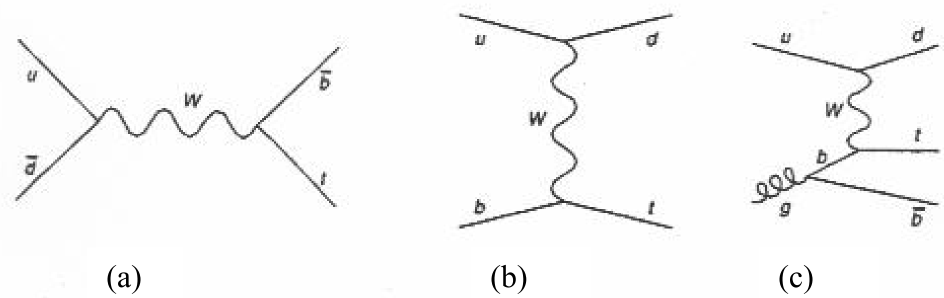

Figure 1: Representative Feynman diagrams for single top quark production at the Tevatron (a) $q'\bar{q} \rightarrow t\bar{b}$ s-channel production; (b) $q'b \rightarrow tq$ t-channel production; and (c) $q'g \rightarrow tq\bar{b}$ t-channel production.

The Standard Model predicts that the top quark decays almost exclusively to a W boson and a bottom quark $B(t \rightarrow Wb) \approx 1$. The rate for the process leads to a firm prediction for the top quark decay width Γ_t. A direct measurement of Γ_t is of great importance, because the width would be affected by any non-expected decay modes of the top quark, whether they are observed or not. Unfortunately, Γ_t cannot be directly measured in the $t\bar{t}$ sample at hadron colliders, but its main component can be accessed through single top processes. If there are only three generations, the unitarity constrain of the CKM matrix implies that $|V_{tb}|$ is very close to unity. But, the presence of a heavy fourth generation quark with a large CKM coupling to the top quark could be consistent with large values of $B(t \rightarrow Wb)$, while resulting in an almost entirely unconstrained value for $|V_{tb}|$. A direct measurement of $|V_{tb}|$ can therefore explore the possibility of a fourth generation, and confirm that the top quark discovered at the Tevatron is indeed the SU(2) partner of the bottom quark.

As can be seen from the diagrams, the single top production cross section is proportional to $|V_{tb}|^2$. A measurement of the single top quark production cross section therefore provides the only known way to directly measure $|V_{tb}|$ at a hadron collider. The best measurement of $|V_{tb}|$ at the Tevatron collider is expected[10] to come from the s-channel single top process $q\bar{q}' \rightarrow W^* \rightarrow t\bar{b}$. Although the cross section for the s-channel is less than half that of the t-channel (0.88 pb vs 2.44 pb @ 2TeV), the s-channel has several theoretical advantages[11]. The process proceeds primarily via valence quarks at moderate values of x, where the quark distribution functions are relatively well constrained. In addition, the partonic fluxes can be constrained from data by measuring initial state effects in the similar Drell-Yan process $q\bar{q}' \rightarrow l\nu$ [12], thereby reducing the uncertainty. The next-to-leading order corrections for s-channel single top production have been available[13] for several years. Calculations of a fully differential cross section at next-to-leading order for the t-channel single top production became available very recently[14], resulting in a cross section that can be more reliably calculated, with a smaller dependence with the choice of scale. The precision on the theoretical cross section is expected to be dominated by the uncertainty in the bottom quark parton distribution function[15], which affects primarily the t-channel cross section. Additional uncertainties of 4% for the s-channel and 15% for the t-channel due to ud- and qg- fluxes, respectively, need to be included. Although both the s- and t-channel single top production will be used together to measure $|V_{tb}|$ during Run2a ($2fb^{-1}$), the most precise method for measuring $|V_{tb}|$ during Run2b ($15fb^{-1}$) is to work exclusively with the s-channel, as the smaller theoretical error is expected to be comparable to the experimental uncertainty from such large data set[16]. The limiting factor on the precision of the measurement of $|V_{tb}|$ from the s-channel signal would therefore be statistical. At the LHC, the cross section for the s-channel process is more than an order of magnitude less than the one for the t-channel, and the cross section for the associated production mode is intermediate between the two. The suppressed cross section for the single top s-channel production, in addition to the overwhelming background arising from the gluon-gluon interaction, will make the direct measurement of $|V_{tb}|$ from the s-channel single top production an extremely challenging task at the LHC. The precision on $|V_{tb}|$ measured from the t-channel at the LHC is expected to be worse[17] than the one achievable from the s-channel at the Tevatron Run2.

The proposed physics research project is the direct measurement of the magnitude of the CKM matrix element V_{tb} from s-channel single top events at the Tevatron. The proposed method will result in the most precise measurement of $|V_{tb}|$ achievable in the foreseeable future.

Experimental Method

As already stated, the single top quark production cross section $\sigma(t)$ is proportional to $|V_{tb}|^2$. Since the top quark decays before it can be detected, experiments actually measure the top quark production cross section times branching ratio of the top decaying into a W boson and a bottom quark:

$$\sigma(t \to Wb) = \sigma(t)\, B(t \to W^+b).$$

Since $B(t \to W^+b) \le 1$, measuring $\sigma(t \to Wb)$ provides a lower limit on $|V_{tb}|$. This lower limit can be turned into an equality by combining the measurement of $B(t \to W^+b)$ from $t\bar{t}$ events[18] with a measurement of $\sigma(t \to Wb)$ from the single top analysis . The goal is therefore to measure $\sigma(t \to Wb)$ for a single top signal that corresponds to the s-channel production, and determine $|V_{tb}|$. The program needed to achieve that goal can be briefly summarized in the following steps. Approximate dates for each of the items is indicated.

1. Develop techniques to extract a $t\bar{t}$ pair signal using the first 500-1000 pb^{-1} of data and the Run2a silicon tracker. Contribute to the R&D and design phase of the DØ Run2b silicon tracker. In particular, develop testing techniques to ensure the quality of the silicon detector modules and set up the testing stations in preparation for the detector construction. (2003)

2. Isolate a single top quark signal with 2-4 fb^{-1} of data (Run2a). Participate in the production and testing effort of the DØ Run2b silicon tracker. (2004-2005)
3. Develop techniques to isolate the single top s-channel signal using DØ Run2b data, primarily by concentrating on identifying jets that originate from a bottom quark using the Run2b silicon tracker. (2006)
4. Measure $|V_{tb}|$ using the s-channel single top signal and the large amount of data available during Run2b. (2007-2008)

Although eventually both leptonic decay channels of the W boson will be combined, the identification of muons and electrons, as well as the sources of instrumental backgrounds, are quite different between the two channels. The rest of this proposal will therefore concentrate in the electron channel.

The primary source of physics background to the top signal comes from W boson events that are produced together with Jets. The dominant source of instrumental background comes from multijet events, where one or more of the jets fluctuates to fake an electron. Some multijet events also have significant ME_T due to fluctuations and miss-measurements of the jet energy that could fake a neutrino from the W boson decay. Figure 2 shows the jet multiplicity distribution as measured by DØ during Run1[19] for events with one high transverse energy electron and high ME_T (triangle points) and $t\bar{t}$ Monte Carlo (hatched histogram), after initial selection cuts. As can be seen, the signal to background ratio is very low. It is therefore necessary to further exploit the differences between signal and background, to extract the signal from underneath the overwhelming background. The most obvious differences are in the event topology and the presence or absence of a bottom quark.

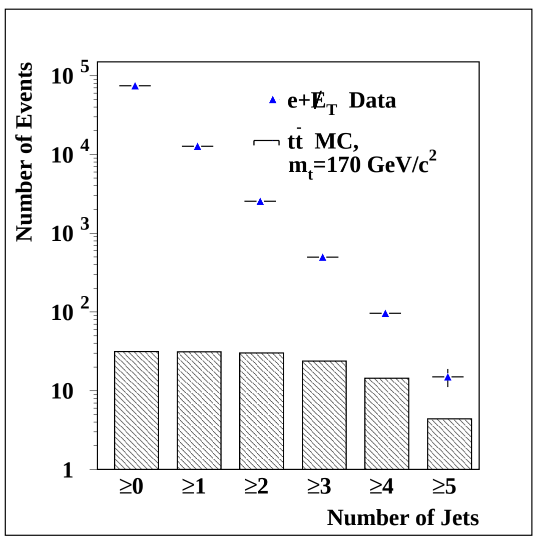

Figure 2: Jet multiplicities for DØ Run 1 $e\nu$ data (triangles) and Monte Carlo simulated $t\bar{t}$ events (hatched histograms).

Although the Tevatron Run2 officially started March 1st, 2001, only a fraction of the Run1 integrated luminosity of physics-quality data has been collected by DØ so far[20], and considerable work still remains to be done to improve the level of understanding of the detector and the object identification. For instance, detailed studies done during Run1[21] on the level of multijet QCD background to W+Jet signals showed that the signal to background ratio could be increased significantly by selecting electrons based on a multivariate discriminant that combined information from several subsystems of the DØ detector. Most of the systems used during Run1 have now been replaced[22], so a new discriminant needs to be developed. In addition, preliminary studies indicate that using a discriminant for the ME_T could improve the rejection of events with large mismeasured imbalance of energy in the transverse plane[23], in particular for events with 2 Jets in the final state, as those expected in the single top s-channel process. After perfecting the electron and ME_T selection, DØ should be able to extract a $t\bar{t}$ signal using topological cuts. This top quark enriched sample can then be used to perfect the b-tagging techniques to select b-quarks originating from top quarks with high efficiency and small fake rate.

Concurrent to these data analysis centered activities, the proposed program includes activities related to the design, R&D and construction of the Run2b silicon tracker. This detector will be the single most important piece of apparatus in the measurement of $|V_{tb}|$ from the s-channel single top signal, and a thorough understanding of its characteristics is imperative to achieve an efficient b-tagging.

As can be seen in Figure 1a, the s-channel process has a $\bar{b}$ quark produced together with the top quark. After the top quark has decayed to Wb, the final state is $Wb\bar{b}$. Although previous studies[24] considered that the dominant t-channel process is the interaction of a W boson, radiated from a light quark, with a bottom quark from a gluon splitting into a $b\bar{b}$ pair (Fig. 1c), new developments[14] indicate that the dominant process is the interaction of a light quark with a bottom quark from the sea (Fig. 1b). The final state therefore has a light quark, and the top quark. After the decay of the top quark, the final state is Wbq. The s-channel single top production could therefore be identified by isolating events where a W has decayed to electron/neutrino, and two rather central, high p_T b-quarks are present.

Jets originating from b-quarks have been identified in the past at DØ by isolating the muon that originates from the semileptonic decay of the b- or the c-quark[19] (Soft Lepton Tag, SLT). Approximately 22% of the time, a decaying b-quark will yield a muon either directly or through a sequencial decay via a c-quark. The same is true for the b-quark producing an electron. These leptons are much softer than the leptons originating from a W boson decay, and they are close to a jet (i.e. non-isolated). Their detection efficiencies are therefore significantly lower than for high p_T isolated leptons. During Run1, the b-tagging probability for SLT at both DØ and CDF was about 20%[25]. Another method of tagging b-jets profits from the relatively long lifetime of B mesons, which causes them to travel of the order of a few mm, before decaying. b-jets can therefore be identified by looking for secondary vertices, a few mm apart from the primary interaction vertex in the transverse plane of the detector[26]. For b-flavored particles with energies expected from top quark decay, the mean decay length is 2 mm, and the mean impact parameter is roughly 250 μm. Thus, efficiently and cleanly identifying these decays requires a detector with the ability to reconstruct tracks with an impact parameter resolution in the tens of microns. The most feasible technology for this is silicon microstrip detectors, like the ones being used in the DØ silicon trackers.

DØ is currently developing a simple b-tagging algorithm[27] that does not rely on the secondary vertex reconstruction. For each track in a jet, one can compute the distance of closest approach of the track to the beam line in the transverse plane (d), and its standard error (σ_d), determined by propagating the fitted track errors to the point of closest approach. One then calculates the Signed Transverse Impact Parameter Significance $\sigma = \pm\, d/\sigma_d$. The sign is assigned from the projection of the point of closest approach onto the jet axis. σ is predominantly positive for real b-decays. Displaced vertices with negative σ are due primarily to track mismeasurements. A jet is tagged as originating from a b-quark if there are at least 2 tracks with $\sigma > 3$, or at least 3 tracks with $\sigma > 2$. The b-tagging efficiency ε_b is defined as the ratio of the number of tagged b-jets to the total number of b-jets. The mistagging rate ε_f is defined as the ratio of the number of tagged u/d-jets to the total number of u/d jets. Using a similar method a b-tagging efficiency of approximately 40% was achieved by CDF during Run1[28].

Run 2 feasibility studies[2] assumed a b-tagging efficiency of 60%, with a mistag rate of about 1%. Dr. Chabalina's studies show that for the current design of the DØ Run2b silicon tracker, the average ε_b per jet is 69%, 19% higher than for the Run2a detector. This is a consequence of the improved impact parameter resolution due to the presence of layer 0 close to the beam pipe. The b-tagging efficiency is above 70% for $|\eta|<1$, reflecting the high track reconstruction efficiency for jets in that region. It decreases with increasing $|\eta|$ to 45% at $|\eta|=2$. Dependence of the mis-tagging rate on the jet $|\eta|$ was studied using Z boson decays to first generation quarks. The mis-tagging rate is of the order of 1% and shows no $|\eta|$-dependence within errors. Figure 3 shows the degradation of ε_b as a fraction of non-functional silicon sensors in the detector. It is clear from this study that high quality silicon detector modules are essential to be able to achieve the b-tagging performance needed for the proposed study. An important part of this proposal is therefore the contribution of Prof. Gerber's group to the development of the Run2b silicon tracker. It is imperative to monitor the quality of the detector modules strictly and uniformly during production, to achieve a fraction of working detector modules in the final tracker close to 100%. Over 95% of detector modules are fully functional in the current Run2a silicon tracker. The experience gained by Prof. Gerber during the construction of this device is being applied to the testing effort of the Run2b silicon tracker. Details about these activities can be found in Prof. Gerber's MRI proposal[29] and in the Silicon Tracker technical design report[30], and will not be included in this document.

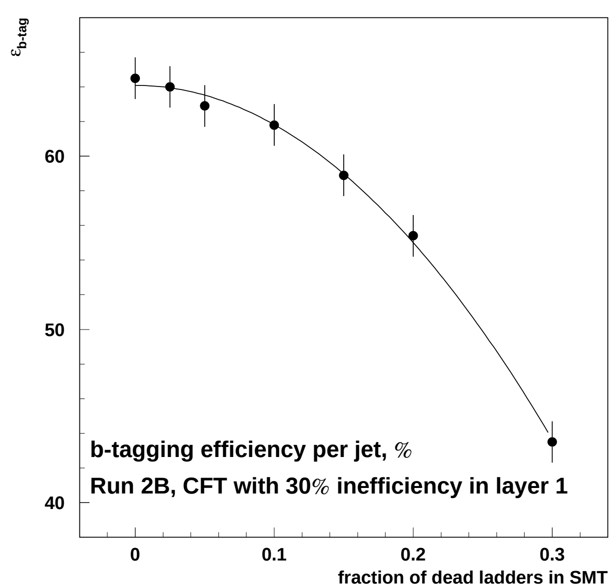

Figure 3: Degradation of b-tagging efficiency per jet as a function of the fraction of non-functional silicon detector modules.

As stated above, the single top s-channel process $q\bar{q} \rightarrow t\bar{b}$ yields the final state $Wb\bar{b}$. There are several background processes that must be considered in order to extract the signal. The primary backgrounds to the s-channel single top signature arise from W ($\rightarrow e\nu$) + 2 Jet events, and QCD production of three-jet events where one jet is misidentified as an electron and the ME_T is an artifact of jet energy mismeasurement. Detailed understanding of the production of W bosons with jets, reduction of QCD multijet background faking $e\nu$ signals, and excellent b-tagging, are crucial to isolate the signal from the background. Once the electron and ME_T identification have been optimized, and two b-jets are efficiently tagged per event, the dominant irreducible background to the signal will come from W bosons that are produced together with two b-quarks by means of the process $q\bar{q} \rightarrow Wb\bar{b}$. With the W boson decaying to an electron and a neutrino, there is no obvious way of separating this background from the signal. One possibility that needs to be explored is the fact that the invariant mass of the W boson plus the b jet M_{Wb} should equal the mass of the top quark for the signal, whereas is should show a continuous spectrum for the $Wb\bar{b}$ background. Unfortunately, one does not know a priori which b jet originates from the top quark decay. Furthermore, the W boson momentum is reconstructed from the electron momentum and the ME_T, which yields a two-fold ambiguity. This ambiguity, combined with the two possible assignments of b-jets, results in four different values of M_{Wb}. Topological characteristics for signal and background need to be studied using Monte Carlo simulated events to try to develop a method that would allow the correct reconstruction of M_{Wb} for signal events.

The second largest background originates from $t\bar{t}$ pair production. This background can be reduced by rejecting events with an additional W boson. If the W boson decays hadronically, the event can be rejected by vetoing on additional jets. This would also reduce the background originating from t-channel single top production. If the W boson decays leptonically, the event can be rejected by vetoing on additional high p_T leptons. Most of the remaining background originates from events where the leptons from the second W boson are not reconstructed. An attempt to reconstruct M_{Wb} could provide an additional handle to separate signal from background. Other backgrounds that need to be considered are Wjj (where jj denotes a light quark or gluon jet), $WZ \rightarrow Wb\bar{b}$, and, if the depending on the Higgs Boson mass, $WH \rightarrow Wb\bar{b}$. The Wjj background can be reduced to a negligible level with double b-tagging. The WZ and WH background could, in principle, be reduced by applying a cut in the invariant mass of the $b\bar{b}$ pair. Topological differences between these backgrounds and the s-channel signal need to be investigated.

It is clear that the ability to identify the b-jets from top quark decay is the crucial first step in reducing the backgrounds to a manageable level. The combination of double b-jet identification, reconstruction of masses, and additional topological considerations will be needed to improve the signal-to-background ratio and isolate a signal. The study of all these aspects of the problem form the bases for this career advancement proposal. The experience gained by Prof. Gerber during the development of the proposed activities will be directly applicable to her long term plan of studying the properties of the Higgs Boson with the CMS detector at the Large Hadron Collider accelerator at CERN, Switzerland.

Integrated Education and Outreach Activities

As already described, the UIC HEP group has been heavily involved in NSF funded QuarkNet outreach activities for the last three years, and has secured additional funding from the Illinois State Board of Education (ISBE) for the project. A central goal of the UIC QuarkNet program is to provide a table-top, High Energy Physics particle detector for each participating high school teacher, for use in their high school classroom. To that effect, the UIC QuarkNet group has developed a setup to measure the muon lifetime. The apparatus is self-contained, portable, and capable of detecting high-energy charged particles. The data is sent to a standard PC for further analysis. Each of the 13 UIC QuarkNet teachers assembled such a detector during the 2001 summer workshop. The active element of the detector is a chunk of clear plastic scintillator that releases a small amount of blue light when a charged particle goes through it. A photomultiplier tube amplifies the light into a small electrical current that serves as input to a self-contained, portable, electronics board, specifically designed for QuarkNet by a group of Fermilab engineers, the UIC HEP faculty, and collaborators from the University of Rochester. The electronics consists of several stages: discriminator, coincidence logic, timing buffer, processor, and data output to computer. The latest version of this board has recently been designed to include a Global Positioning Satellite (GPS) time stamp allowing detectors running in separate locations to correlate data to a precision of 20ns, and muti-hit time measurements so the width of a pulse and precise timing of hits at that particular detector site can be recorded. The amount of energy in the detector, not only the presence of a charged track, can then be determined. These two new features will allow sites collaborating in the NSF funded North American Large Area Time coincidence Array (NALTA[31]) to look for extended air showers by analyzing data taken at various sites across North America. In addition, the UIC HEP group has build one muon telescope experiment, to measure the distribution of Cosmic Rays by measuring the direction of the muons that reach the Earth's surface. The telescope is made out of two counters; by requiring that both counters fire at the same time, the approximately direction of the incident muons can be obtained. The setup is installed on a movable table to measure the rate of muons as a function of the angle of the two detectors with respect to the vertical. The complete setup is controllable remotely via a web interface developed by an UIC undergraduate student (Kyle Burchesky). In addition, data taken by the UIC setup for the muon lifetime experiment is also available on the web.

An integral part of Prof. Gerber's career advancement proposal is the continuation and expansion of her Quarknet activities, as summarized below. Illinois State Board of Education funds are available until 2005.

1. Commission 16 new detectors with a new HV base that uses a setup to generate AC power from a regular car battery for greater portability.
2. Verify Einstein's Time Dilation with a field trip to the top of the Sears Tower and a dedicated airplane flight. Kyle Burchesky is training as a commercial pilot, and will take detectors with him during his training flights.
3. Expand the UIC QuarkNet web-based setup to measure the muon lifetime and the distribution of cosmic rays. Remote high schools could participate in the experiments even if they themselves do not have a detector at their institution.
4. Set up a web based repository of data collected by detectors at various high schools. This would allow students to compare different data sets and learn to work as part of larger scientific collaboration.

5. Set up a Large-Array experiment with four detectors separated by several meters that will be triggered and readout together. The setup will be used to measure the rate of cosmic ray showers that hit all four detectors at once.
6. Build and commission a Pb-glass detector as part of the large array experiment. The Pb-glass does not scintillate, but is sensitive to Cerenkov radiation given off by particles traveling faster than the speed of light in glass. This project will introduce QuarkNet participants to the light equivalent of a sonic boom where sound waves build up because an object is moving faster than sound in the air. The Pb-glass previously used at a Fermilab experiment that measured proton-antiproton annihilations is available for the project.
7. Investigate the feasibility of contributing to the understanding of extended air showers by placing large-array detectors in weatherproof enclosures on the site roof at individual high schools in the Chicago area. This activity would allow for collaboration with former argentine colleagues of Prof. Gerber, currently involved in the Pierre Auger project[32], and collaborations with the NALTA consortium[31].

These activities would allow the participation of high school students, teachers, and college undergraduates in a multi-faceted, hands-on research effort to study extended cosmic-ray air showers. High-energy ($E > 10^{18}$ electron volts) cosmic rays continuously strike the earth's atmosphere from outer space creating avalanches of daughter particles that cover areas up to 50 square miles on the earth's surface. Prof. Gerber's plan is to use the large array particle detectors developed by the UIC HEP group for their QuarkNet program, and place them in numerous locations, for example on the rooftops of high schools around the city of Chicago. With this extended array, measurements of the original cosmic ray energy and incident direction can be made. Students from each high school will be responsible for maintaining the detectors and monitoring the data collected at their site. Different sites will be logically connected to each other making an effective cosmic ray detector array. The aim of the project is to develop an expanding set of high-school teams who construct, implement, and operate their school-based detectors in coordination with physics professors, graduate students, and undergraduate physics and science-education majors. Exposure to this project could potentially lead a larger number of high school students to major in a scientific discipline.

Prof. Gerber's silicon hardware project and interest in top quark physics are another aspect of her ongoing outreach and educational efforts. Within the Run2b upgrade project, Prof. Gerber collaborates closely with the group lead by Prof. Alice Bean from the University of Kansas (UK) and with Prof. Raymond Hall from the California State University at Fresno (CSUF). UK received funds through the EPSCoR program for the project, and an undergraduate engineering minority student (Joni Jorgenssen) is working closely with Prof. Gerber's students to set up a hybrid testing station at UK. CSUF is a non-Ph.D. granting institution, that offers physics education up to the Masters level. Prof. Hall secured NSF funds to engage one of his students in the silicon Run2b project by testing ceramic hybrids locally at CSUF. The proposed activities therefore enhance the infrastructure for research and education at these institutions, and provide a means for students to come in contact with state-of-the-art equipment and hands-on experience with basic science research projects. Both Profs. Bean and Hall are members of the DØ top physics group lead by Prof. Gerber.

The UIC silicon lab has been modernized with the latest readout electronics for SVX chips using MRI matching funds. The lab regularly hosts visits from undergraduate engineering and science students from Prof. Gerber's classes. Together with material from general High Energy Physics outreach sites (particleadventure.org and Fermilab Inquiring Minds), it provides the perfect setting to introduce visitors to the frontier research in Particle Physics, and to immerse undergraduate students into the exciting world of basic research. The modern electronic equipment now available at the UIC silicon lab provides practical training opportunities for UIC undergraduate and graduate students participating in the project.

The DØ Collaboration has proven to be extremely effective in disseminating the findings of its research broadly, by publication of basic physics and technical articles[1], presentation at international conferences[33], and thorough description of activities in internal DØ experiment notes[34]. The DØ experiment has made available to the general public the *Plain English Summaries*[35] for their physics results, and has pioneered making DØ data available to non-members of the collaboration through Quaero[36]: a web based, quasi-model independent strategy to search for new physics in high transverse momentum data taken by DØ during Run1. All these practices will continue for results based on Run2 data.

Prof. Gerber's commitment to improve teaching has been recognized by the UIC Council for Excellence in Teaching and Learning (CETL) that granted financial support for a Curriculum and Instructional Grant to renovate undergraduate teaching labs. Matching funds from the physics department and the college of liberal arts and sciences were secured for this project. The labs will be completely renovated and computerized, and Prof. Gerber is one of the leading faculty members involved in the design of new experiments for the topics of electricity, magnetism and optics.

Summary

A five year CAREER advancement plan has been laid out that would allow students and post-docs working with Prof. Gerber to acquire a balanced education in the field of Experimental High Energy Particle physics by combining activities in data analysis and detector design, construction and operation. In addition, her proposed QuarkNet outreach program would provide a vehicle for people at many levels - from the high school student to the university professor – to contribute to an exciting, basic research and education initiative.

The proposed physics research project would lead to the first observation of top quark production at hadron colliders via the electroweak production of a single top from a Wtb vertex. The measurement of the CKM matrix element $|V_{tb}|$ using the described method is expected to have the highest precision achievable with existing accelerators in the foreseeable future. Observing single top quark production and understanding the top quark couplings is one of the priorities of the High Energy Physics program. Prof. Gerber's experience and current activities put her in a unique position to take a leading role in this scientific enterprise.

The proposed educational and outreach project follows Prof. Gerber's tradition of involving and collaborating with members of underrepresented groups in her research activities. The project is a perfect extension to funded activities already undertaken by Prof. Gerber, and would contribute to her recognition as one of the leading experts in silicon trackers and high p_T physics processes. The experience gained during Run2 at the Tevatron would allow her to take a leading role in the search for the Higgs boson at the CERN pp Large Hadron Collider (LHC) scheduled to start operations in 2008.